PHYSICS-BASED MODELING OF HIGH-FREQUENCY GROUND MOTIONS AND PROBABILISTIC SEISMIC HAZARD ANALYSIS

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EXECUTIVE SUMMARY

A research collaboration, led by the Southern California Earthquake Center (SCEC), which includes earth scientists, engineers, and computer scientists, used Blue Waters to run physics-based earthquake simulations that improve our understanding of earthquake processes and their effects on seismic hazard. SCEC's earthquake system science research program develops detailed earth models and high-performance computing software needed to perform realistic, physics-based earthquake and ground motion simulations. This past year, the SCEC team used NCSA Blue Waters to develop more accurate and scalable computational models of earthquakes and to calculate the first physics-based probabilistic ground motion forecasts for Central California.

RESEARCH CHALLENGE

Probabilistic Seismic Hazard Analysis (PSHA) [1] is the scientific framework for many seismic and risk-related engineering and social applications, including performance-based design, seismic retrofitting, resilience engineering, insurance-rate setting, emergency response, and public education. The U.S. Geological Survey (USGS) currently uses empirical PSHA to promote seismic safety engineering and disaster preparedness across the United States, including California. SCEC's research goal is to develop physics-based seismic hazard models for California and elsewhere that are more accurate than the empirical USGS National Seismic Hazard Map Project [2] standard models. Our long-term goal is to extend physics-based PSHA across the full bandwidth needed for seismic building codes and other purposes.

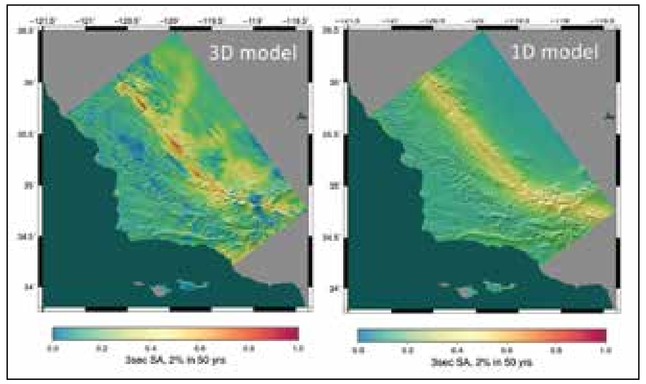

Figure 1: Seismic hazard maps for Central California from CyberShake Study 17.3 when (right) a simple 1D seismic velocity model and (left) a 3D seismic velocity model were used by the CyberShake deterministic wave propagation simulations.

METHODS & CODES

This year, SCEC researchers added improved physics into our wave propagation software and improved our software's performance on CPUs (central processing units) and GPUs (graphics processing units). For high-frequency ground motion simulations, our codes must model frequency-dependent attenuation [3], free-surface topography [4], and nonlinear yielding effects [5]. With improved codes and support through the Blue Waters PAID program, we performed the first 4-Hz nonlinear magnitude 7.7 earthquake simulation using 4,200 GPUs on Blue Waters [5,6] using a highly optimized implementation of a nonlinear computational method developed by SCEC researchers. We continued to validate our software by simulating well-recorded historic California earthquakes and comparing our simulations against the recorded ground motions [7].

Also this year, we used Blue Waters to perform CyberShake Study 17.3. This study applied the CyberShake [8] PSHA computational method to Central California for the first time. Study 17.3 calculated two seismic hazard models for Central California: one using a traditional 1D seismic velocity model and the other using a more accurate 3D velocity model, with results shown in Fig. 1. Results using the 3D velocity model show ground motion levels in the California Central Valley that are markedly lower than the levels produced from the standard ground motion prediction equations (GMPEs) currently in widespread use by earthquake engineers. This is in marked contrast to our results in Southern California, where CyberShake predicts stronger shaking than the GMPEs in the deep, low-velocity sedimentary basins. The differences are related to the lateral extents of the basins, which govern their resonance frequencies and amplitudes. These results provide new evidence that CyberShake's physics-based approach can substantially improve our estimates of strong ground shaking.

We are preparing selected research codes to run efficiently on next-generation supercomputers. We have improved the performance of our wave propagation and Strain Green Tensor codes on next-generation GPUs and Xeon Phi systems [9]. To scale up the I/O performance of our software along with our improved compute performance, we optimized I/O performance of our anelastic wave propagation (AWP) software by increasing our use of third-party HPC (high-performance computing) I/O libraries including ADIOS, HDF5, and PnetCDF.

RESULTS & IMPACT

CyberShake simulations for Southern California are under review as inputs to a new Los Angeles urban seismic hazard map are under development by the USGS. The SCEC committee for Utilization of Ground Motion Simulations (UGMS) is working within the framework of the Building Seismic Safety Council activities to develop long-period, simulation-based, spectral-response acceleration maps for the Los Angeles region. Our CyberShake hazard maps are under consideration for inclusion in the National Earthquake Hazards Reduction Program, the American Society of Civil Engineers 7–10 Seismic Provisions, and for the Los Angeles City building codes. The UGMS group is using CyberShake simulations to quantify the effects of sedimentary basins and other 3D crustal structures on seismic hazard—information that is difficult to obtain with traditional empirical methods. Prototype risk-targeted maximum considered earthquake (MCER) response spectra have been mapped using a combination of the empirical approach and the CyberShake model and are being integrated into the National Institute of Building Sciences' Project 17 recommendations for tall buildings. It is no overstatement to say that our sustained work on Blue Waters is transforming and modernizing earthquake science and engineering, and thus represents a major contribution to Strategic Goal 1 (Transform the Frontiers of Science and Engineering) of the NSF 2014–2018 Strategic Plan [10].

WHY BLUE WATERS

SCEC's earthquake system science research program needs access to Blue Waters' scale computing resources for several reasons. SCEC computational research requirements continue to expand in many ways including in terms of algorithmic sophistication, geographical range, and time resolution. New simulations require more computational, memory, and storage resources. Our computational demands continue to grow because our calculations do not yet span the full range of resolution parameter space, not all important physics have yet been included, and because individual earthquake simulations do not "solve" a problem when run just once or twice. Great uncertainty remains in the ground motions expected in future earthquakes, and society would be remiss in delaying a better resolution of such a critical scientific and public safety challenge.

PUBLICATIONS AND DATA SETS

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